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APPLIED RESEARCH, INC.

ANALYSIS OF ELECTRO-OPTIC MATERIALS PROPERTIES ON GUIDED WAVE DEVICES

FINAL REPORT

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Applied Research Inc.

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ANALYSIS OF ELECTRO-OPTIC MATERIALS PROPERTIES ON GUIDED WAVE DEVICES

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This report summarizes the support of ARI personnel to the development, test and analysis of waveguide structures which have potential use in integrated optical devices.

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1.0 INTRODUCTION

The objective of this work has been to support the research and development effort in the design, construction and testing of electro-optical components for signal processing and sensor devices in missile applications at the Weapon Sciences Directorate, MICOM. The application of electro-optic components will improve the optical and electrical performance of missile and radar guidance.

Applied Research, Inc. personnel have been working out fabrication techniques, developing device structures, and building and testing devices in a number of materials. In addition to the older established materials such as GaAs, InP, and doped glasses, new photopolymers have been examined for their optical and electrical characteristics.

2.0 POLYMER DEVICES

Several electro-optic (EO) polymer devices were made and tested under the previous task, "Measurement Techniques for Optical Guided Wave Designs." The testing of two materials, TS-2 and OL-2, begun during that task were also completed. OL-2 was intended for use as a buffering layer to prevent degrading reactions between the EO polymer TP18 and the Norland overcoat, but its resistivity was too high. Although OL-2 could not be used as intended, its resistivity made it ideal for electrical isolation of individual devices in a multi-layer sample. It is now used instead of Norland for isolation under the second device's ground plane (Figure 1).

The TS-2 thermoset material's electro-optical activity was no better than that of previous materials, but it does have a significantly higher operating temperature (Tg=210 C).

Dow has provided another EO polymer, TP32, and it appears to have an activity similar to the old TP7 polymer. TP32, however, does have a higher operating temperature (Tg=160 C). Another polymer, P2ANS/MMS 50:50, provided by Celanese has been used in a device, and optical testing should begin shortly. This polymer, mixed 20% w/v TCP, yields a good coating. However, cyclohexanone is preferred because it allows the spinning of multilayers without intermediate buffering layers. But the procedure for dissolving the polymer in cyclohexanone is very complex. It is hoped that Celanese will be willing to mix it up for ready use. The Celanese materia's Tg is low (140 C), but it is hoped that it's electro-optic activity will be higher than that of previous materials.

Photobleaching techniques have also been used with TP7 and TP18. Several TP7 waveguides have been produced but, as of yet, no devices. The photobleaching technique does not involve the production of a structural waveguide. Guides are created by photo-chemicals changing the index of the material (Figure 2). This technique promises to make waveguide fabrication easier and quicker. Device fabrication will begin shortly.

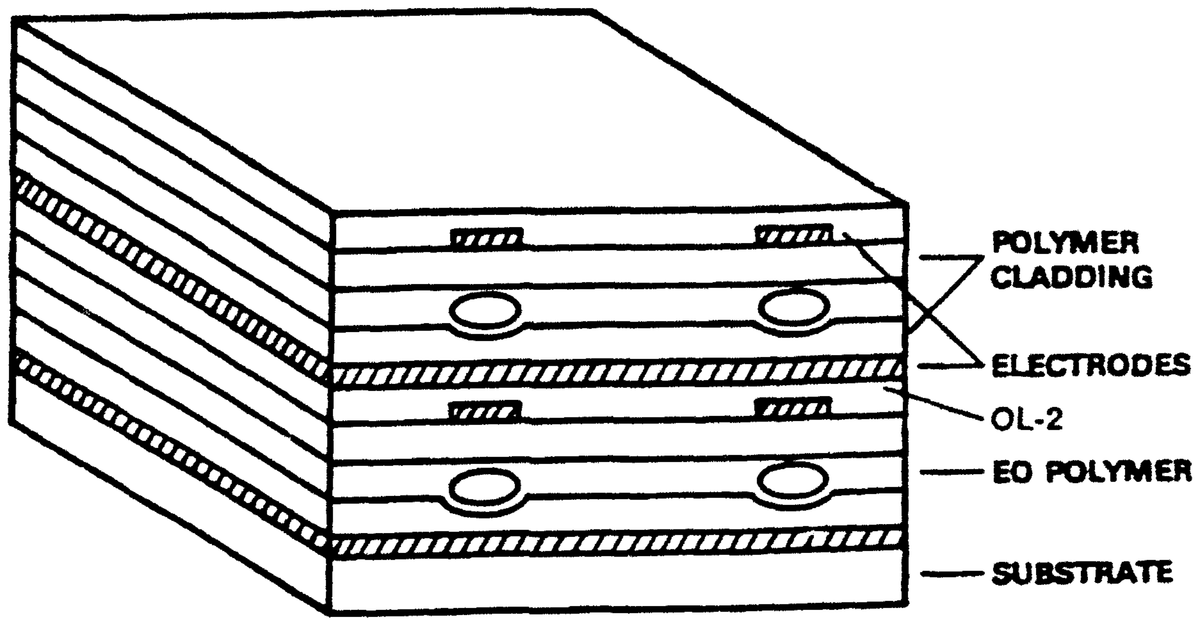
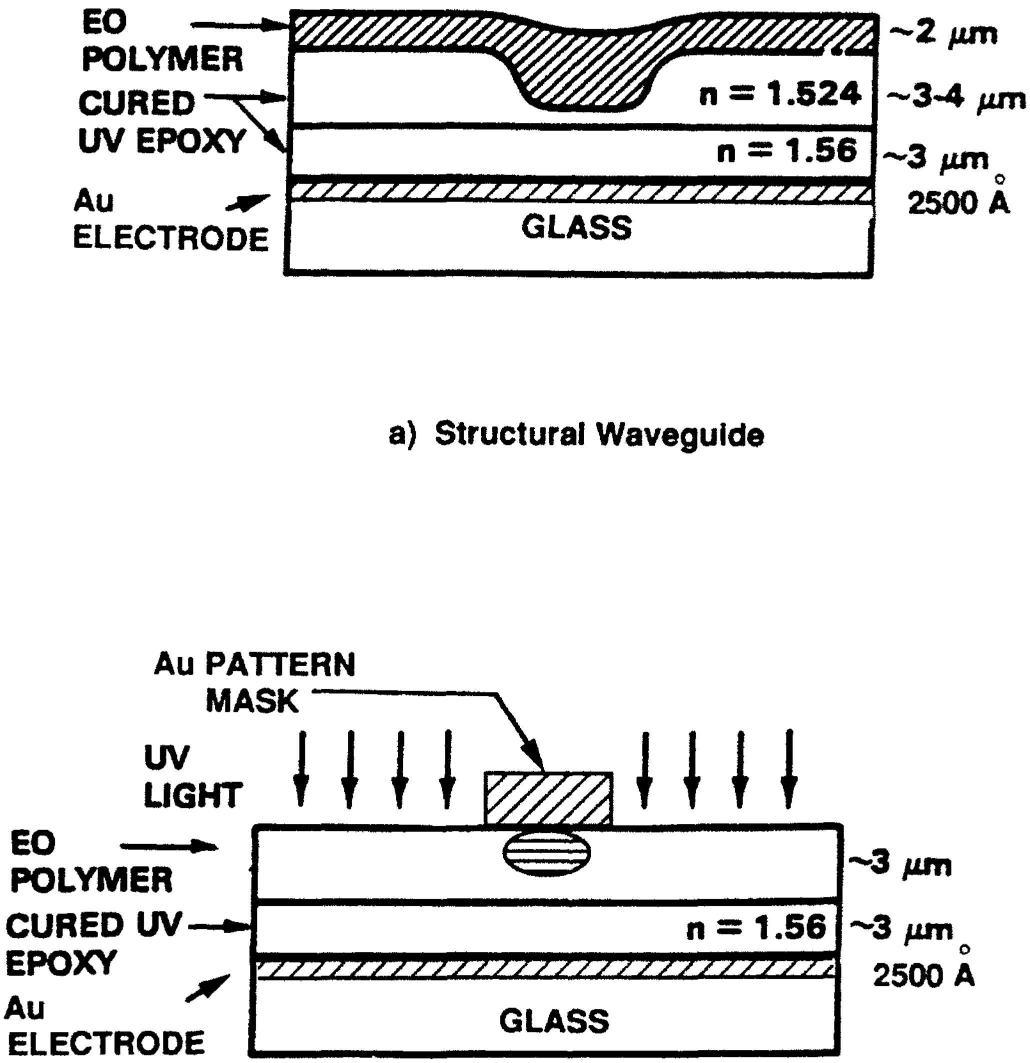


FIGURE 1



a) Structural Waveguide

b) Photobleached Waveguide

FIGURE 2

3.0 GaAs MULTIPLE QUANTUM WELLS

All of the objectives for electro-optical measurements in GaAs multiple quantum wells have been met, and the results are being summarized for publication in a refereed journal. Within this last task, a new imaging and data collection system was installed, measurements on propagation losses in channel waveguides fabricated by different etching techniques were completed, orientation dependence of phase shifts was verified and the non-linear intensity dependent phase shift was measured.

A new high resolution Burle CCD video camera in combination with an SBIG slow scan, TE cooled CCD camera, with an external electronic shutter was installed for imaging waveguide outputs. For phase shift measurements, interference of the waveguide ouput with an external beam (Mach-Zehnder configuration) produced fringe patterns which were imaged onto the high resolution Burle camera. Measurements of electro-optic phase shifts were performed using this camera in conjuction with an automated system developed in a prior task.

Software to acquire data from the photometric CCD camera (SBIG) was completed, along with an interface to an external electronic shutter to prevent streaking during readout and allow integration over a precisely defined time interval. This camera was used for precision measurements of waveguide output intensities to determine propagation losses. The SBIG camera was also used for high S/N ratio measurements of waveguide mode profiles, and for measurement of the intensity dependent phase shift. The camera and shutter system were tested for linear response with integration times ranging from 0.2 seconds to more than 5 minutes.

The fabrication of integrated optics devices in GaAs requires etching to form rib waveguides. Chemical etching is the standard method for fabricating rib waveguides. It produces smooth sidewalls on the waveguides, resulting in low optical losses. However, one drawback of chemical etching is that the etch depth is not controllable to high precision. Reactive-ion etching (RIE) is a more controllable etching technique, allowing etch tolerances of less than 50 angstroms (the tolerance with chemical etching is approximately 500 angstroms). Etch depths are very critical in the fabrication of some integrated optics devices, such as directional couplers. Therefore, it is desirable to know how much propagation losses are increased by using the RIE process, over chemical etching.

Measurements were made of the output mode intensities of channel waveguides fabricated using reactive-ion etching (RIE) with methane or freon as the active species. Waveguide modes were imaged onto the SBIG camera, and the CCD was integrated for a specified interval. The total intensity was computed from the sum of all pixels in a box containing the mode. A background sum was computed and subtracted, before normalizing the data for integration time. This measurement was performed on approximately 50 channel waveguides from four different samples. The normalized results were compared for RIE channels and chemically etched channels.

Chemically etched channels showed the lowest loss (4 dB/cm at 875nm TM), as expected. RIE etched channels had losses of approximately 8 dB/cm for the same conditions Electron micrograph images of the RIE channels showed rough sidewalls.

The roughness is a result of imperfections in the metal mask used to define the channel patterns. While chemical etching tends to smooth out roughness in the original mask, RIE reproduces the original imperfections exactly. With increased care in the original mask fabrication, differences in propagation losses between chemically etched and RIE channels could be reduced even further. These results were presented at this year's Optical Society of America meeting in Albuquerque.

Intensity profiles of channel waveguide modes were also recorded. The camera field-of-view was calibrated with features of known size. Mode profiles were recorded for channels of various widths. A comparison of theoretically modelled mode profiles (for single mode channel waveguides) with the measured profiles showed excellent agreement.

Electro-optic phase shift measurements taken during the previous task revealed a dependence on propagation direction for TE polarized light. The orientation dependence has been extensively re-measured and verified for several waveguide samples. In addition, we were able to identify the crystal planes associated with the two sets of measurement.

Phase shift was voltage data was taken for both orientations on three new 70 A quantum well samples, and for two 95 A quantum well samples. The data was fit to obtain linear and quadratic electro-optic coefficients. Our results show that the linear term is approximately twice as large in the [1, -1, 0] propagation direction as in the orthogonal [1, 1, 0] direction for 70 A well samples. The quadratic terms are equal, to within the uncertainty of the measurements, in both directions. Samples from two different wafers exhibit this phenomenon, which has not been reported in the literature. One curious result is that the asymmetry in the linear coefficient does not appear in data taken for 95 A quantum wells. At the moment, there is not a physical model to account for the asymmetry.

Also investigated was the presence of intensity dependent phase shifts (arising from chi-3). The phase shift at a given voltage was measured as a function of input laser power. The power was varied over seven orders of magnitude, from less than 1 nanowatt up to 10 milliwatts. Below 100 microwatts, the phase shift was unchanged. Non-linear effects began to appear (i.e., the phase shift began to change) at input powers of around 1 milliwatt. It was seen that apparent non-linear effects could be observed at low powers also (around 1 microwatt) if good electrical contact was not established with the sample. Field screening due to photo-induced charges, which can't drain off with a bad contact, is probably responsible for a low power non-linear behavior.

The comprehensive set of measurements on 70 A quantum well samples is being compiled in a paper to be submitted for publication. This paper will include a number of measurements, taken over the past two years, on exciton absorption spectra, current-voltage data, electro-absorption data, electro-refraction data, mode profile measurements, planar waveguide propagation losses, and non-linear intensity dependent phase shifts. Measurements on channel waveguide losses will be published separately.

The results obtained thus far establish a baseline for future work in semiconductor integrated optics devices. While quantum wells provide sizable electro-optic effects, bulk semiconductor waveguides (GaAs/AlGaAs) operating at longer wavelengths have lower optical losses, and are easier to fabricate. For sensor applications such as the fiber gyro, bulk semiconductor waveguide devices may prove more suitable, since propagation loss is a critical issue. We have now begun to transition to longer wavelength (1.3 microns) measurements for testing bulk semiconductor waveguides. Modifications will have to be made in the imaging and data collection systems and new laser sources will have to be set up. These are some of the goals which remain to be pursued in future efforts.